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Image Resolution Computation for Ultra-Wideband (UWB) Synchronous Impulse Reconstruction (SIRE) Radar

by Lam Nguyen

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14. ABSTRACT
This report describes the approach used to compute the down-range and cross-range resolution for the U.S. Army Research Laboratory synchronous impulse reconstruction (SIRE) radar. The results determine the upper bound in term of resolution that the radar can achieve (for targets along the center line of the physical receiving antenna array). These results are needed for the computation of the calibration factor for this radar.

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Ultra wideband radar, synthetic aperture radar (SAR), forward imaging radar

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1. Introduction

In support of the U.S. Army vision for increased mobility, survivability, and lethality, the Microwave Branch at the U.S. Army Research Lab has developed a new version of the low frequency ultra-wideband (UWB) synthetic aperture radar (SAR) to support forward imaging applications (*1*,*2*).

This report describes the approach used to compute the down-range and cross-range resolution for the SIRE radar. First, the results determine the upper bound in term of resolution that the radar can achieve. Second, these results are needed for the computation of the calibration factor for this radar.

2. Standard Narrow-Band SAR Resolution Computation

The closed-form formula to compute the down-range and cross-range resolution for side-looking SAR is widely available from the literature (*3*).

The down-range resolution is given by

$$\Delta_{range} = \frac{c}{2B} \tag{1}$$

where c is the speed of light and B is the bandwidth of the radar signal.

The cross-range resolution is given by

$$\Delta_{cross-range} = \frac{d\lambda}{2L\cos^2\theta} \tag{2}$$

where d is the distance from the radar to the target, λ is the wavelength of the radar signal, L is the aperture length, and θ is the squinted angle from the radar to the target. For broadside target, $\theta = 0$.

These standard equations for the computation of the SAR resolution can only be used for a rough estimation of the SIRE radar resolutions. Equation 2 was derived for radar with (a) narrow frequency band, (b) monostatic configuration, and (c) one-dimensional SAR processing. In reality, our radar is based on an ultra-wideband technology and λ varies significantly from low-end frequency to high-end frequency. In addition, in equation 2, d represents a distance from the radar to the target. However, in our image processing algorithm, we form the SAR image using a two-dimensional aperture (*2*), in which radar data from a physical antenna array (to provide cross-range resolution) are coherently integrated while the radar moves forward. Thus, the

distance d from the radar to the target varies as we integrate data in a forward direction for image formation. Finally, SIRE has a bistatic configuration with 16 receivers and two transmitters (*2*).

3. SIRE Radar Resolution Computation

This section describes the approach used to compute the down-range and cross-range resolution for SIRE radar. First, we use the SIRE radar simulator to generate the radar data for a point target. Second, we filter the radar data for each frequency band of interest and form the corresponding SAR image. Finally, range and cross-range resolutions are measured from the point target's SAR image.

We have developed a radar simulator to support various trade-off studies regarding the SIRE radar performance (*4*). Using the simulator, we can easily change the radar configurations such as number of receivers, transmitters, aperture size, bandwidth, etc. and predict the corresponding radar performance. Given the radar configuration, the geometry of the radar path, and the locations of an array of targets, the simulator generates backscatter signals from these targets. The source of the backscatter signal could be an analytical response from a point target or a response from an object based on rigorous electromagnetic computation. The resulting radar data is then processed using the signal and image formation algorithms we developed for SIRE.

For this study, we generate a point target with the following analytical expression

$$p(t) = \cos(2\pi f t)\exp\left(-(\alpha f t)^2\right), \qquad (3)$$

where f is the center frequency, and α is a constant that determines the bandwidth of the signal. Figure 1 shows both the time domain and frequency domain responses of the point target. Note that the signal frequency response ranges from under 500 MHz to over 2000 MHz. This should cover the frequency band that SIRE supports. In practice, the frequency bands of interest are subsets of this band. Thus, it is advantageous to use this set of data and filter according to specific frequency bands. Figure 2 shows the time and frequency domain responses of the same point target but filtered using the frequency band 500 MHz to 2000 MHz.

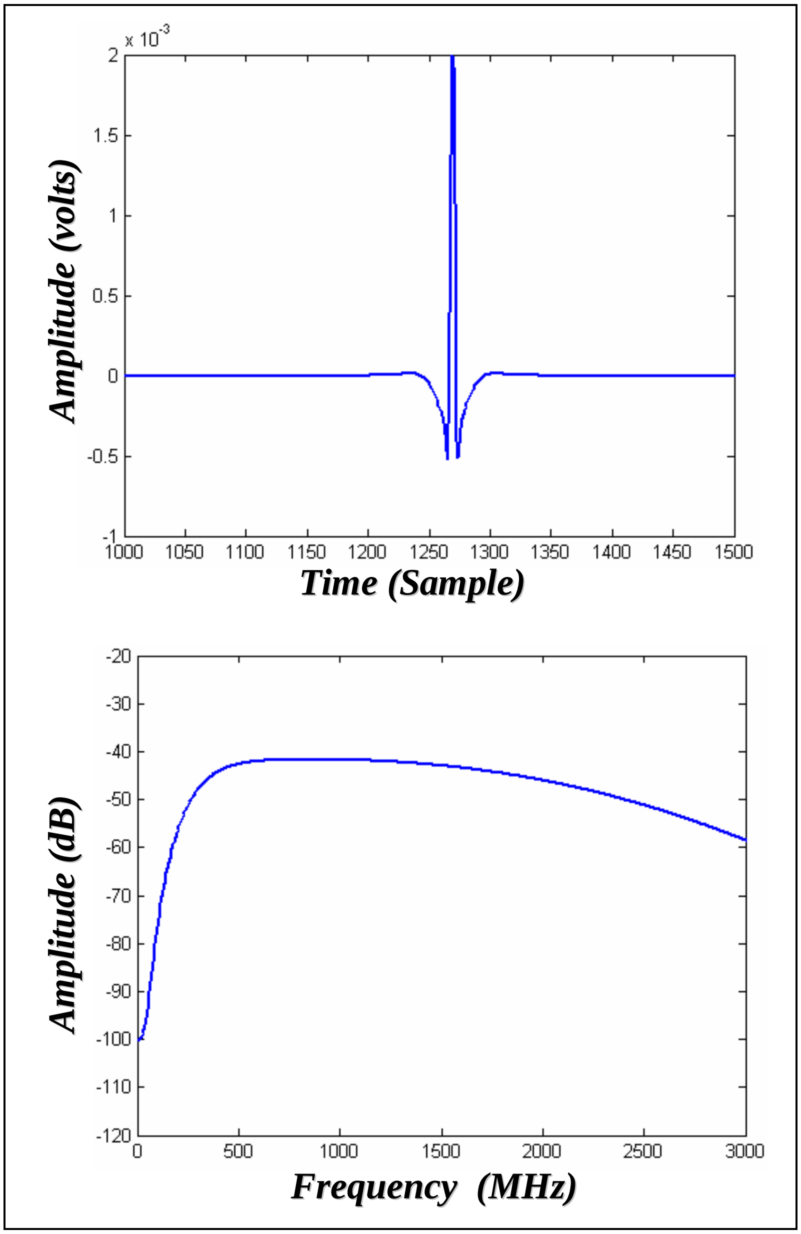

Figure 1. Point target in time domain and frequency domain.

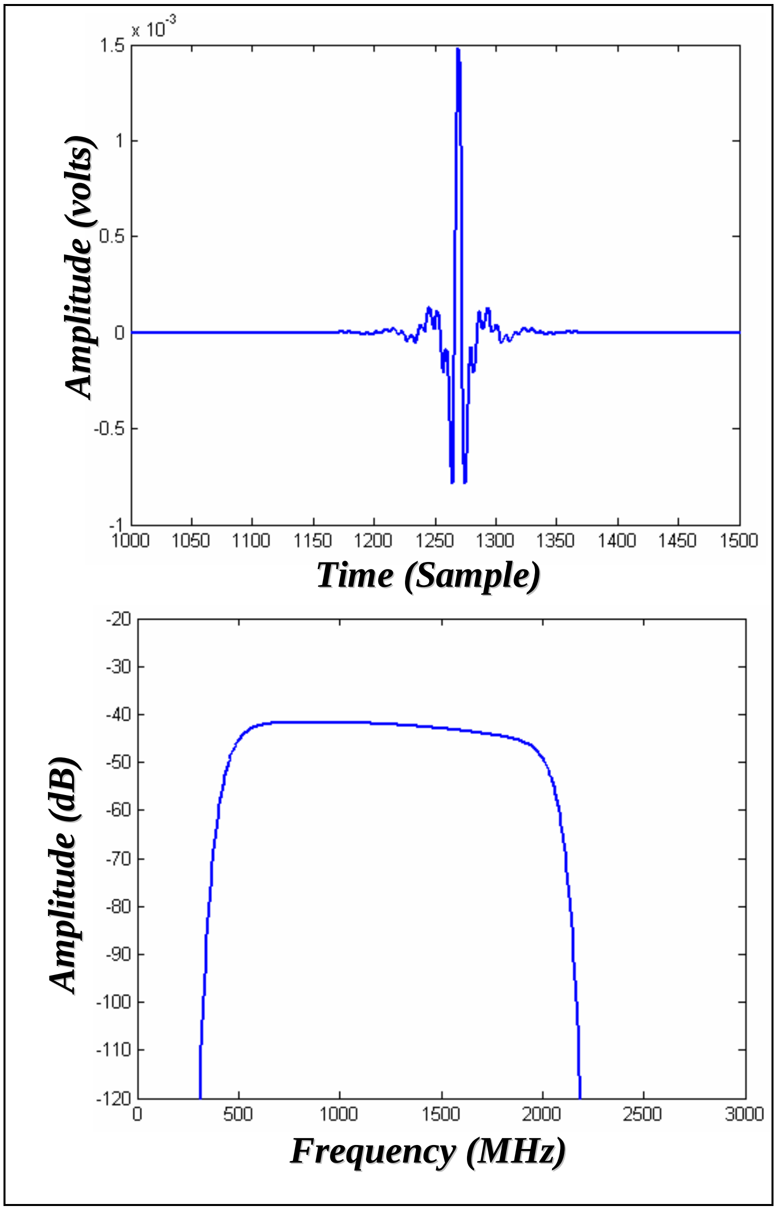

Figure 2. Point target (filtered using frequency band 500-2000 MHz) in time domain and frequency domain.

Figure 3 shows the simulation geometry. A point target is located at coordinates (0,0) m. The radar starts 20 m in front of the target. Note that the radar starts transmitting using the left transmitter (red + on the left of the array) and digitizing backscatter signal using 16 receivers. The radar then moves forward and transmits using the right transmitter (red + on the right of the array). The radar continues moving forward while repeating this process until the radar stops at 10 m in front of the target. The physical receiving array of the radar combines with the forward motion (synthetic aperture) to form a two-dimensional aperture. The imaging process coherently integrates data from this two-dimensional aperture to produce the SAR image (*5*). The imaging

process is beyond the scope of this report and will be described in future publication. Figure 4 shows the SAR image for this point target for the frequency band 500 to 2000 MHz.

Figure 5 shows the down-range and cross-range profiles of the point target. The –3 dB lines cutting through the range and cross-range profiles determine the corresponding resolution.

Figures 6 through 13 shows the SAR images of the point target filtered at various frequency bands and the corresponding range and cross-range profiles.

Table 1 list the range and cross-range resolutions for the SIRE radar in five different frequency band.

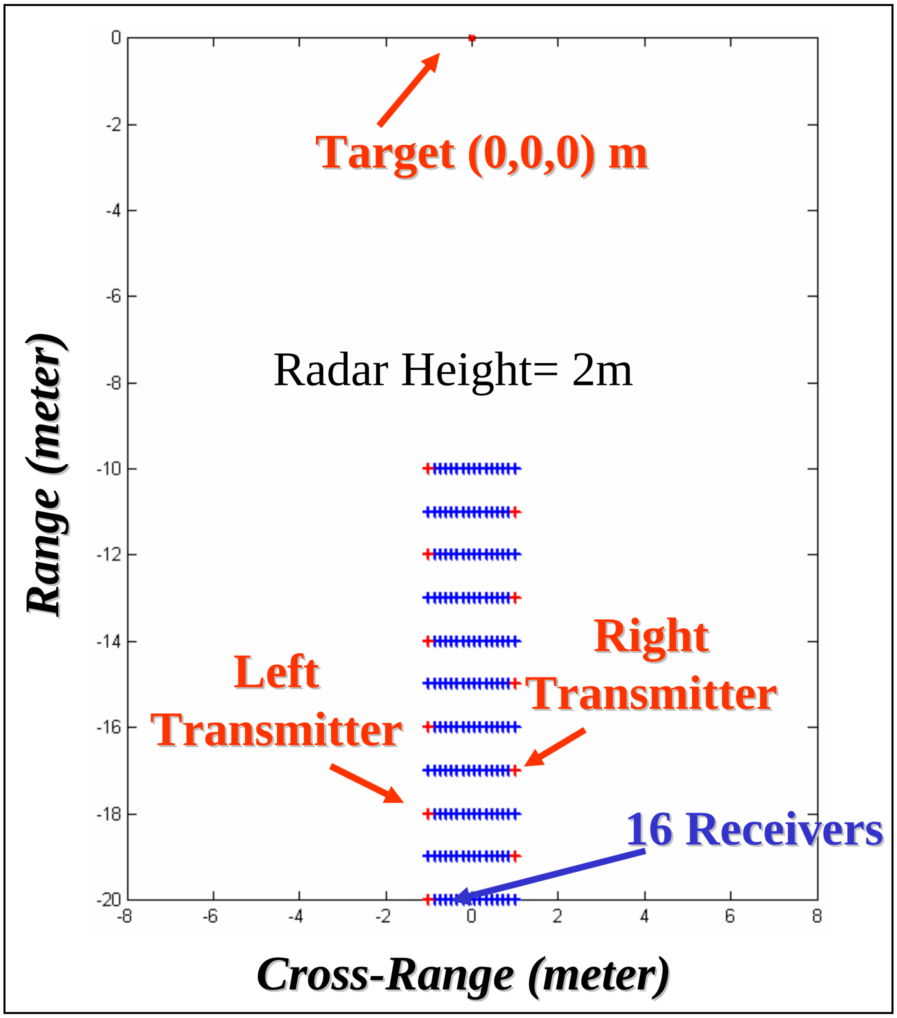

Figure 3. Simulation geometry.

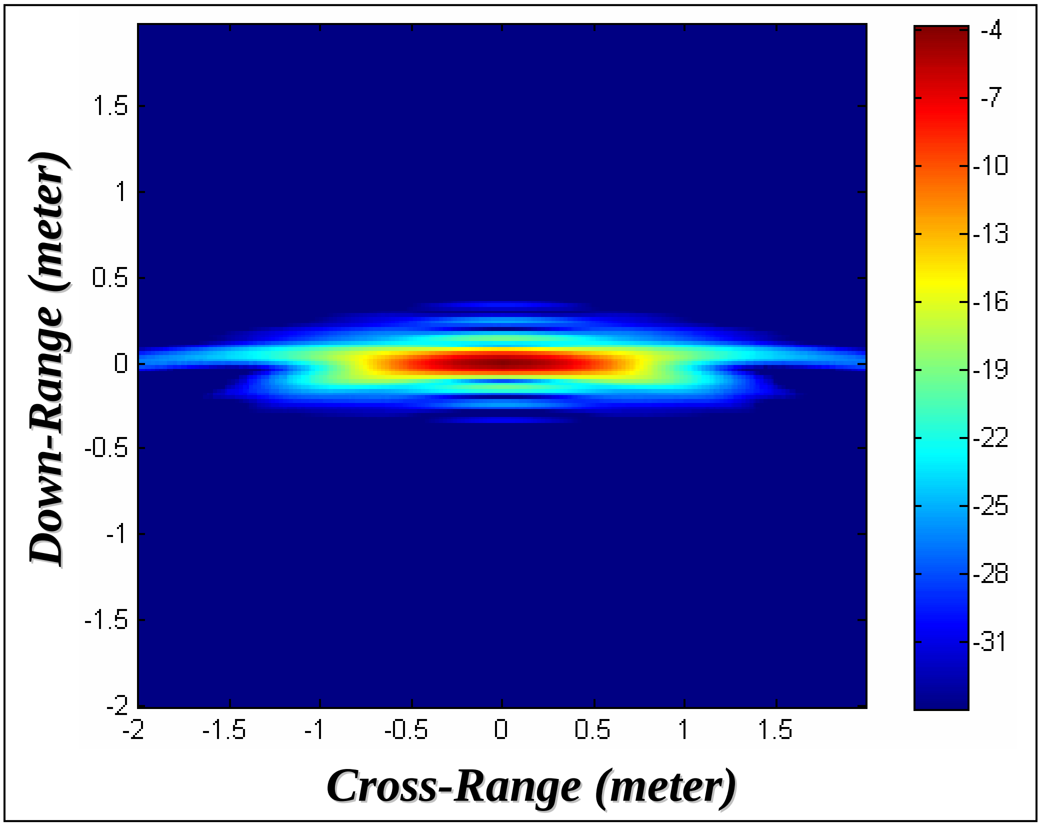

Figure 4. SAR image of a point target (500-2000 MHz).

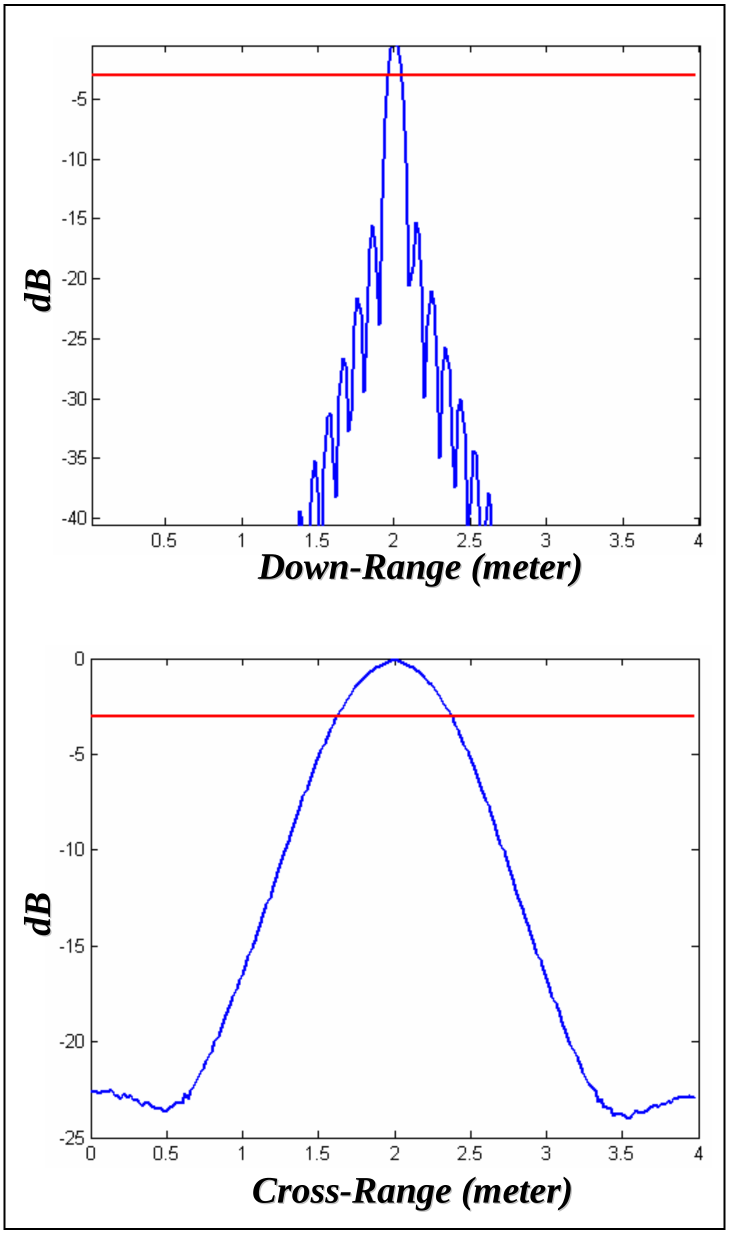

Figure 5. Range and cross-range profiles of a point target (500-2000 MHz).

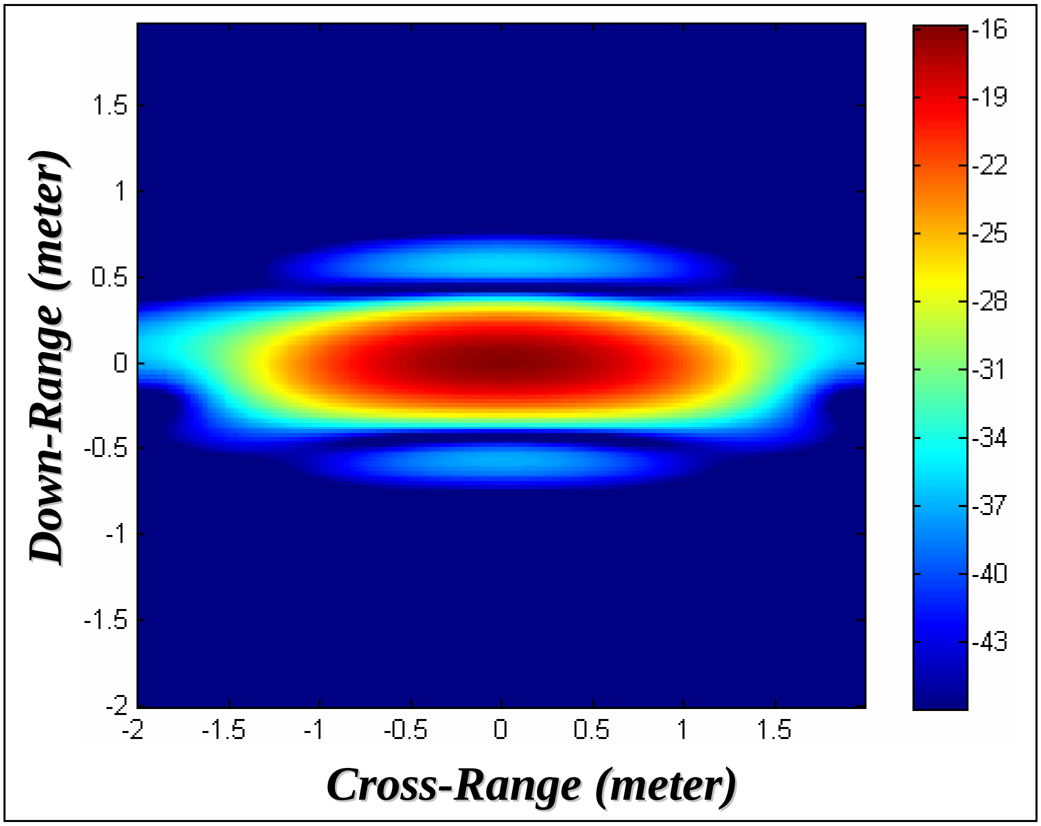

Figure 6. SAR image of a point target (500-800 MHz).

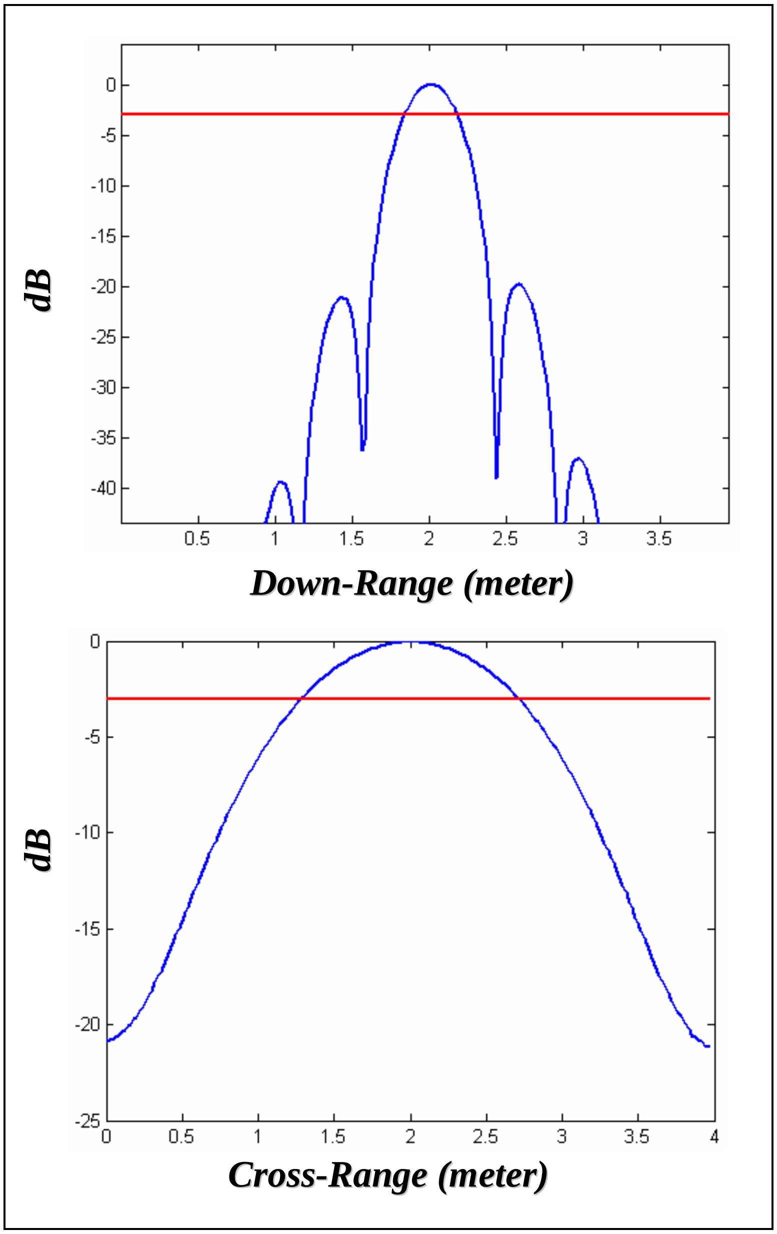

Figure 7. Range and cross-range profiles of a point target (500-800 MHz).

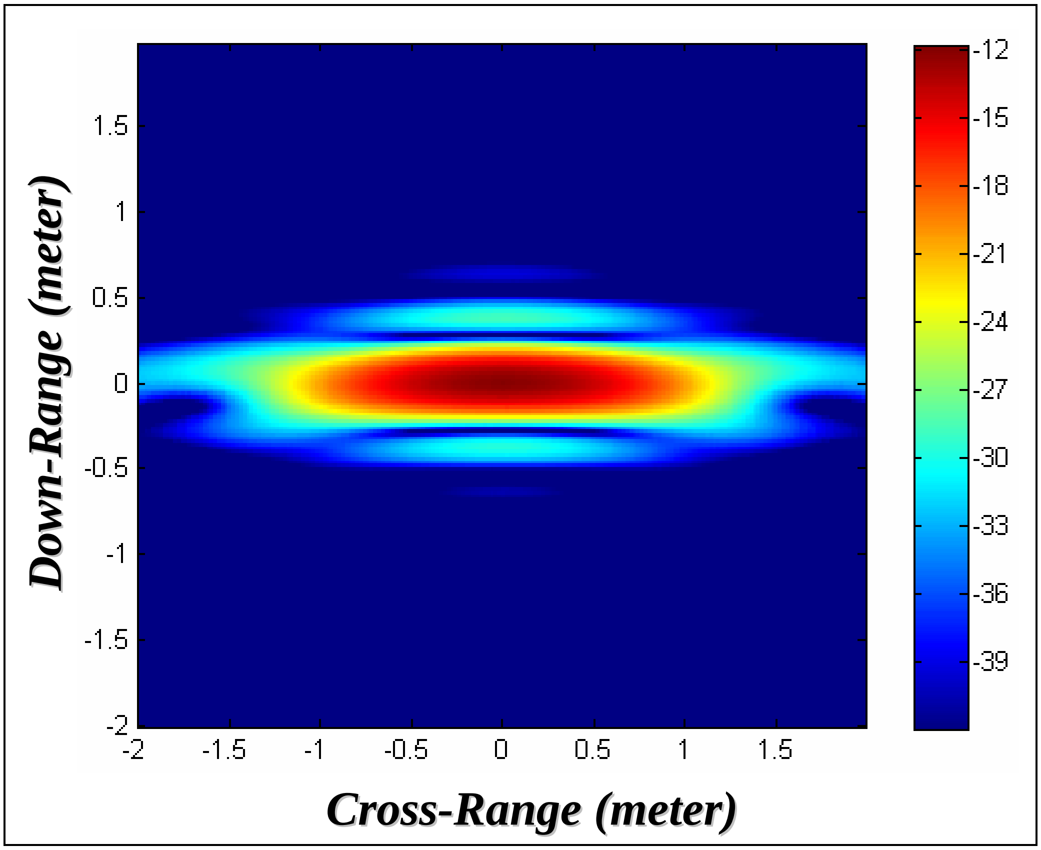

Figure 8. SAR image of a point target (500-1000 MHz).

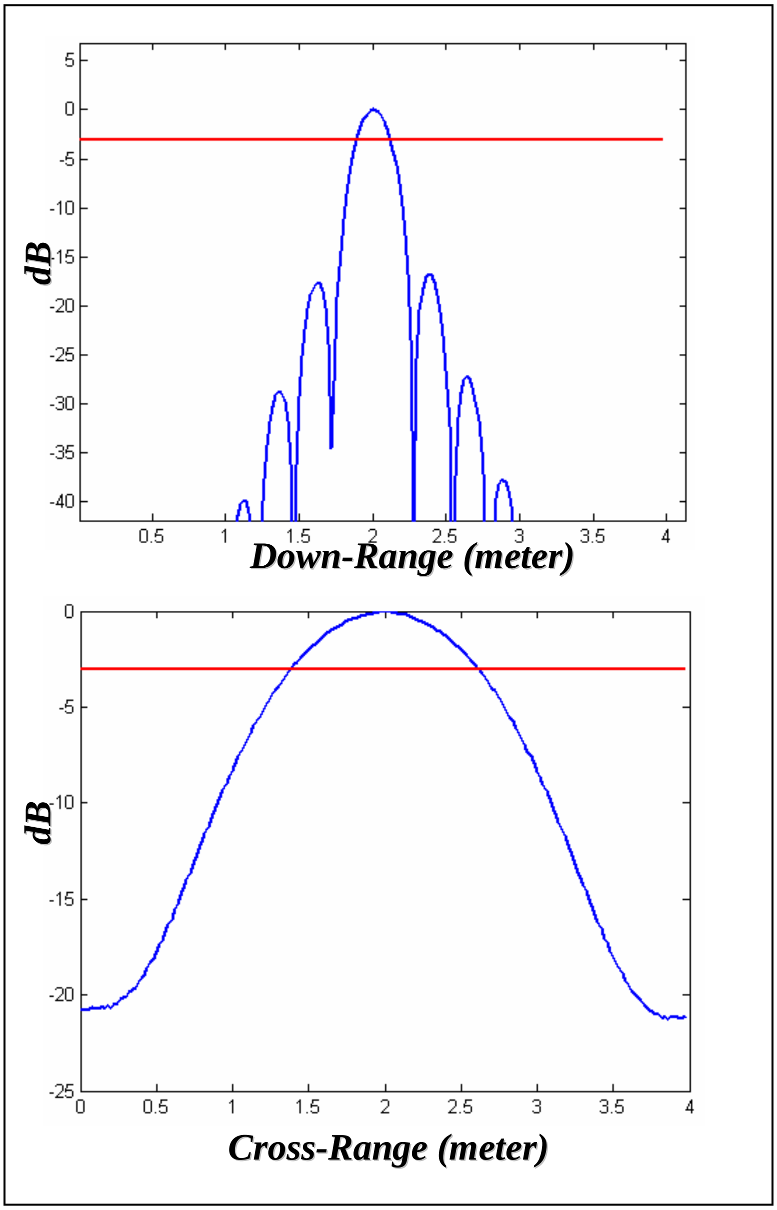

Figure 9. Range and cross-range profiles of a point target (500-1000 MHz).

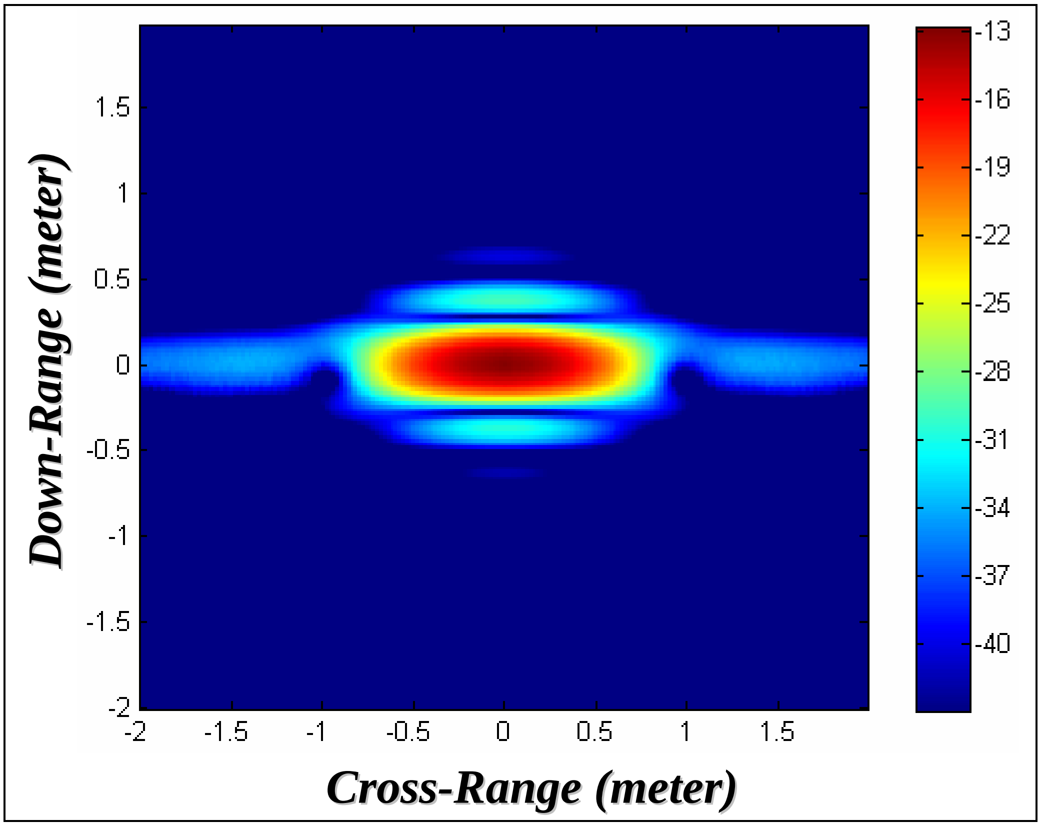

Figure 10. SAR image of a point target (1000-1500 MHz).

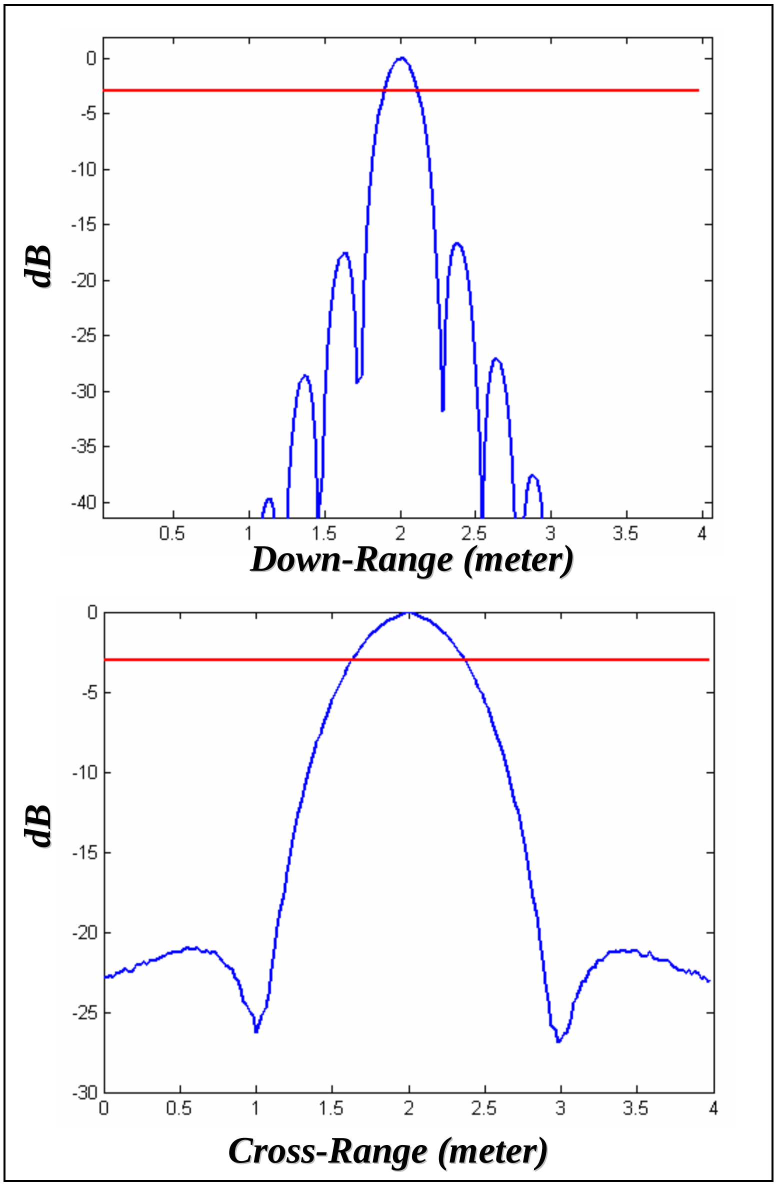

Figure 11. Range and cross-range profiles of a point target (1000-1500 MHz).

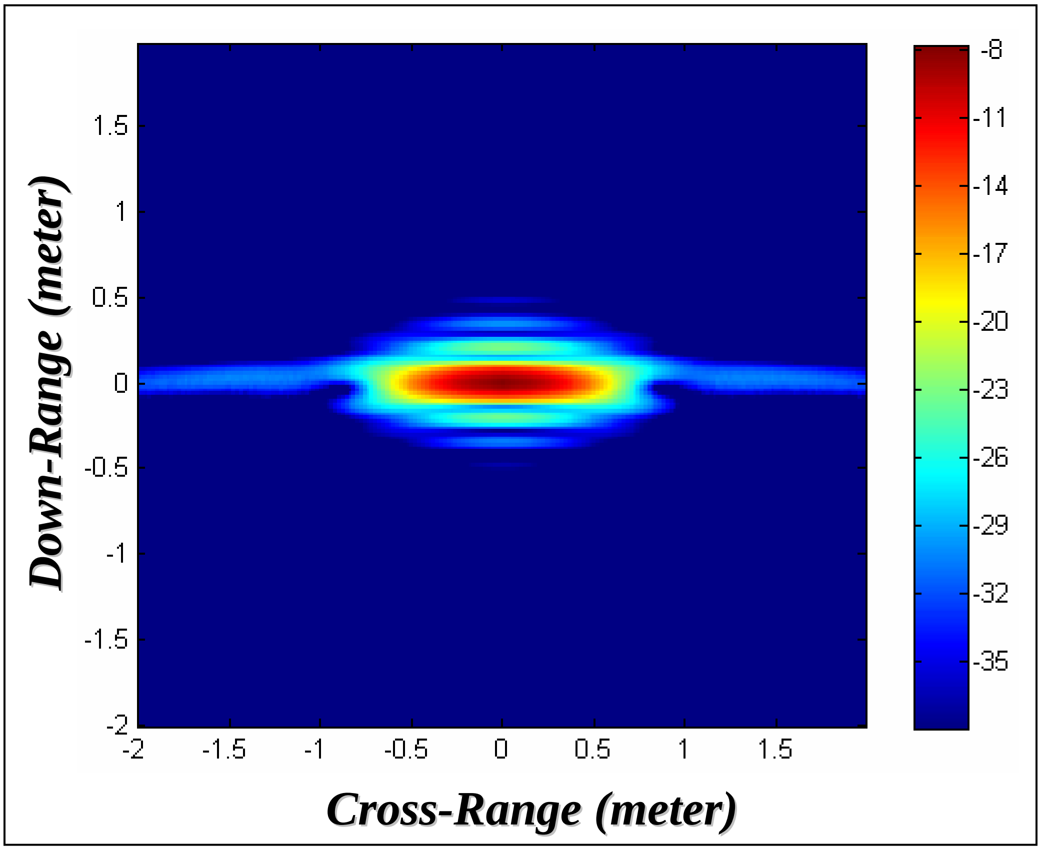

Figure 12. SAR image of a point target (1000-2000 MHz).

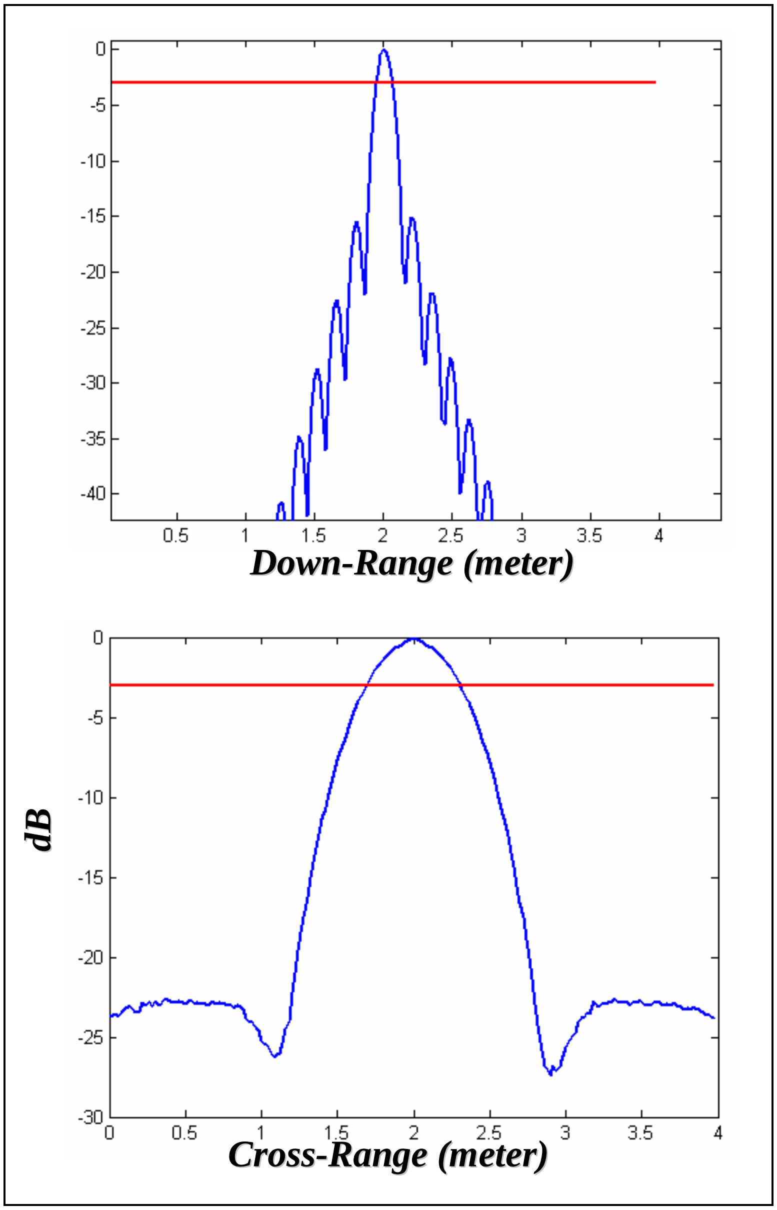

Figure 13. Range and cross-range profiles of a point target (1000-2000 MHz).

Table 1. Range and cross-range resolution for SIRE radar in different frequency bands.

Frequency Band	**Range Resolution (meter)**	**Cross-Range Resolution (meter)**
500-2000 MHz	0.086	0.744
500-800 MHz	0.342	1.428
500-1000 MHz	0.228	1.224
1000-1500 MHz	0.224	0.736
1000-2000 MHz	0.124	0.616

4. Summary

We have described the approach used to compute the range and cross-range resolution for the SIRE radar. The technique employs simulation that depends on radar configurations, geometry, and frequency band. We have listed the results for a particular configuration and geometry. These results determine the upper bound resolution performance the SIRE radar can achieve. These results are also needed to compute the calibration factor for this radar.

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